THE EMERGENCE OF A KNOWLEDGE AGGLOMERATION: A SPATIO-TEMPORAL ANALYSIS OF INTELLECTUAL CAPITAL IN INDIANA

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Abstract. U.S. States and communities increasingly compete for intellectual power so as to thrive toward an economically vibrant setting that spurs the entrepreneurial spirit and attracts businesses and industries from around the world. . The study traces the educational attainment levels of county residents between 1970 and 2000, and addresses three questions: Did the distribution of intellectual capital across Indiana counties change over time and does it differ from the distribution across all U.S. counties? Do brain-rich areas concentrate in space and did the degree of concentration increase over time? Are degree of rurality and accessibility related to an area's ability to accumulate intellectual capital? The analysis shows that educational deprivation in Indiana is widespread and has been persistent over the last three decades. Spatially, the highly educated population increasingly concentrates in the center of the state. By the year 2000 a knowledge agglomeration has emerged that contributes to an increasing spatial disparity of intellectual capital across Indiana's counties. The analysis further suggests that growth of the knowledge population is favorably influenced by closeness to the knowledge agglomeration, but negatively influenced by rurality and educational deprivation. Moreover, it suggests that counties experience higher growth of their highly educated population if they neighbor counties with a high growth of their knowledge population. These results potentially have far reaching policy implications for regional development in the State of Indiana.

Key Words: Education, Knowledge Workers, Agglomeration, Spatio-Temporal Analysis

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1. Introduction

Over the last decades, we have seen drastic changes in the occupational and educational composition of the labor force in developed countries. These changes are part of a long-term trend toward post-industrial societies in which management and professional jobs – with their reliance on a highly-educated workforce – have gained pivotal importance. Intellectual power has become a force necessary to thrive toward an economically vibrant setting that spurs entrepreneurial spirit, and attracts businesses and industries from around the world (see e.g., Cooke 2002, Karlsson et al. 2004). In fact, Henderson and Abraham (2002) refer to knowledge as the "new fuel powering economic growth in the 21st century" (p. 88).

The United States experienced a remarkable rise in educational attainment, ensuring a head-start in this new competitive environment. However, the education boom did not affect all regions equally. Many states, such as several states in the Midwest, have been less successful in accumulating the intellectual capital that has become so influential in today's economy. In fact, many Midwestern States lose a substantial share of their well-educated residents to other states (Schachter et al. 2003, Franklin 2003, Waldorf 2005). The Midwestern States are made up of rural areas that often dominate the landscape with extensive corn and soybean farming, as well as areas with a strong focus on manufacturing such as the steel industry in Gary, Indiana, and the automobile industry in Detroit, Michigan. The transition to a knowledge-based economy takes on added significance in these areas since their competitive advantages – such as low labor costs in rural areas – continue to erode in the face of ever stronger competition from far away places around the globe. In light of these new economic realities, a failure to accumulate intellectual capital thus threatens their ability to compete and puts them at risk of persistently lagging behind (see, e.g., Lichter et al. 1992, Munnich et al. 2002).

This paper aims at understanding temporal changes in the distribution and accumulation of intellectual capital, using the State of Indiana as a case study. Indiana consists of 92 counties that represent both rural and urban settings. The study traces the educational attainment levels of county residents between 1970 and 2000, and addresses three questions: Did the distribution of intellectual capital across Indiana counties change over time and does it differ from the distribution across all U.S. counties? Do brain-rich areas concentrate in space and did the degree of concentration increase over time? Are degree of rurality and accessibility related to an area's ability to accumulate intellectual capital?

The focus on intra-state spatio-temporal changes is at the very core of this study. The State of Indiana as a whole has been identified as one of the least successful in retaining its

educated residents. However, this paper shows that a state-level perspective hides important small-scale variations and that demographic changes at the county level reveal a less bleak picture than the state-wide aggregate figures suggest. In fact, the analysis uncovers a remarkable peak in the landscape of intellectual capital that can serve as a catalyst for attracting intellectual capital from outside the State. At the same time, the study also shows that a remote location relative the major center of economic activity, technology and innovation severely restricts the accumulation of intellectual capital and that the combined effects of peripheral location and rurality pose an exaggerated threat to the expansion of a knowledge-based work force.

The paper is comprised of four sections. Following this introduction, the second section provides a general background on temporal changes in educational attainment levels in the United States and in the State of Indiana. The third section provides the small-scale analysis of educational attainment within Indiana with a focus on unearthing the temporal changes in the spatial agglomeration of intellectual capital, and testing the rurality and accessibility hypothesis. The paper ends with a summary, implications for future developments and regional economic policies.

2. Background

The long-term shift toward post-industrial societies with an increasing dominance of the tertiary sector and in particular the quaternary sector is convincingly documented by the occupational breakdown of the U.S. labor force over time. Only management and professional occupations have substantially increased their share in the labor force over the last decade. The share of service occupations increased slightly by less than one percentage point. All other occupation categories saw their shares dwindle quite drastically.

The growing quaternary sector requires a highly educated labor force, and we have witnessed a concomitant rise in the educational attainment level of the population.[1] Whereas in 1970 the percentage of persons age 25 and older with at least a four-year college degree was only 10.7 percent, it increased by 5.5 percentage points to 16.2% in 1980, and by additional four percentage points in each of the two subsequent decades (Table 1). Today, about one quarter of the adult[2] population has earned at least a four-year college degree. This remarkable increase at a high speed is accompanied by a comparable decline in the population at the other end of the educational attainment scale, namely those who did not

[1] Unless otherwise noted, the data on educational attainment has been taken from a compilation of U.S. census data by the USDA Economic Research Service http://www.ers.usda.gov/StateFacts/

complete high school. In 1970, nearly half of the adult American population did not have a high school degree. By the year 2000, only one fifth of the population falls into that category. It is reasonable to suspect that much of this drop is simply due to age-related mortality differences between the traditionally less educated older population and the younger, more educated population.

– Table 1 about here –

Compared to the U.S., educational attainment levels in the State of Indiana lag behind: Indiana's percentage of highly educated is far below the national figure. Further, the education gap at the higher end is widening: in 1970, the percentage of the adult population with at least a four-year college degree lagged 2.4 percentage points behind the national average. The gap increased in every subsequent decade and has now reached five percentage points. Compared to other States, Indiana consistently ranked in the bottom 10th percentile of the distribution. Only some southern States (and Nevada) that are traditionally known for their poor educational attainment levels, rank below Indiana. This situation puts Indiana into a difficult position as it tries to build a knowledge-based workforce.

A recent report by the U.S. census reveals that 17 U.S. States have gained intellectual power through the net in-migration of young, single and college educated persons (Franklin 2003). The State of Indiana is among the thirty-three states that have a negative net balance. It even ranks among the bottom ten in its ability to attract this highly valued segment of the population. Moreover, because Indiana is surrounded by states that are equally struggling against what is commonly referred to as brain drain, it is further hampered in its ability to take advantage of knowledge spillovers. Table 2 shows that – with the exception of Illinois – all states in Indiana's immediate neighborhood lose their college educated single population age 25-39. Iowa tops the list with a loss of 22 percent of its single young college-educated population within the five-year period from 1995 to 2000. Indiana ranks second, losing about 14 percent. At this alarmingly high rate, it will take less than one generation to cut this highly valued population segment in half.[3] That is, in 2022 Indiana is predicted to have only 50 percent of the young educated residents that it had in 2000. In Indiana's neighboring states (other than Iowa), the net migration rates of these residents are somewhat lower but severe net losses due to migration prevail.

– Table 2 about here –

[2] Persons of age 25 or older.
[3] This also assumes equal numbers of college-graduates entering and exiting this age-cohort.

The literature suggests that urban areas with their abundance of managerial and professional jobs are often the preferred destinations of the highly educated (Costa and Kahn 2000, Florida 2002, McCann and Sheppard 2002, Ritsilä and Haapanen 2003, Schachter et al. 2003). Indiana with its large share of rural counties thus seems to be particularly vulnerable to outmigration of its educated population. Moreover, as shown in Table 3, only the largest metropolitan areas in the State record a net migration gain for their highly educated population. For example, the Indianapolis metro-area gained nearly three for every two young single college-educated persons lost to other states or other parts of Indiana between 1995 and 2000.[4]

– Table 3 about here –

Indiana's position is further peripheralized due to its economic structure. Not only does Indiana have a large share of rural counties, but with twenty percent of its labor force in manufacturing, Indiana is also the national center of manufacturing activity. Although manufacturing is still the catalyst for much of Indiana's economy, it is also a declining sector nationally and – albeit at a slower rate – at the state level. Indiana thus faces the challenge of diversifying its economic activities toward increasing the share of the quaternary sector, yet the comparatively slow growth of the educated population potentially threatens a smooth progress towards economic development in a globalized world.

3. Small-scale Analysis

Indiana is a Midwestern state, sandwiched between Ohio in the East and Illinois in the West, with a population of about 6.25 million people. It is divided into 92 counties that are quite diverse, varying widely by population size, population characteristics, economic structure as well as topography and environmental features. The population sizes of Indiana counties range from a low of less than 6,000 people (Ohio County in the southeastern corner of the State) to a high of over 800,000 in Marion County, which houses the Capital city, Indianapolis. Seventy-two percent of Indiana counties have less than 50,000 inhabitants. The population size of Marion County is only rivaled by Lake County, which is located in the northwestern corner of the State and is part of the Chicago metropolitan area.

3.1 A Persistent Pattern of Relative Educational Deprivation. In 1970, not having completed high school was almost the norm in Indiana. The percentages of adult residents

[4] Note that the high losses for Lafayette and Bloomington – which house Purdue University and Indiana University, respectively – are typical for small- and medium sized college towns, and are likely inflated due to the very high turn-over rates and definition / accounting of students who enter the area without a college degree but leave the area after having completed a college degree.

not having completed high school varied between 33 and 66 percent. The county average was 49.2 percent, slightly higher than the statewide average of 47.1 percent. On the other hand, having at least a four-year college degree was a rare exception and only applied to about 8.3 percent of the adult population. The county average was only 6.5 percent, with a huge variation from a minimum of 3.1 percent to a maximum of 27.4 percent. As shown in Figure 1, the wide range is solely due to two counties, Tippecanoe County and Monroe County which are home to Purdue University and Indiana University, respectively. Without these two outliers, the variation in the percent college educated adults shrinks substantially and the distinguishing characteristic of the remaining counties is the percentage of poorly educated residents. Moreover, as a general trend, counties with a high percentage of highly educated residents have a low percentage of poorly educated adults, and vice versa. Almost 60 percent of the counties face the least favorable situation of an above average proportion of poorly educated adults and a below average proportion of highly educated. On the other hand, only five counties fall into the upper left quadrant that includes counties with an above average proportion of highly educated and a low proportion of poorly educated adults.

– Figure 1 about here –

Thirty years later, in the year 2000, the situation has changed only in so far as the distribution moved to the left (fewer poorly educated persons) and upwards (more highly educated persons). However, since the national averages moved in the same directions, there are no structural changes and the level of *relative* educational deprivation remains untouched. That is, counties that performed poorly on the educational scale in 1970 also did so in 2000. This persistence, when extrapolated into the future, implies that some counties will be trapped in a state of educational deprivation that will make it difficult – if not impossible – to meet the needs of employers who rely on a knowledge-based workforce.

To assess the extent of persistence, the 92 Indiana counties are grouped into three categories of educational status. Counties categorized as *poor* have an above average percentage of adults without a high school degree, and a below average percentage of adults with at least a 4-year college degree (lower right-hand quandrant of the distribution). In 1970, there were 55 counties falling into that category. By 2000, the number of counties in this category had decreased to 41. Counties categorized as having a *good* educational status have a below average percentage of poorly educated adults and an above average percentage of adults with at least a 4-year college degree. Both in 1970 and in 2000, only five counties fall into this category (upper left-hand quandrant of the distribution). The educational status of all other counties is categorized as *medium* (lower left-hand quandrant of the distribution).

They have a below average percentage of adult residents without a high school degree as well as a below average percentage of adult residents with a college degree.[5]

– Table 4 about here –

Table 4 shows the 10-year transition rates for the educational status of the 92 counties for each decade from 1970 to 2000. There is a 93 percent chance that a county categorized as "poor" in 1970 will continue to be in that same category in 1980. Even more worrisome is that during the 1970s, four additional counties drop into this category of lowest educational status. The chances of a county staying at the lowest educational level remain equally high during the 1980s and then drop to 43 percent during the 1990s. At the other extreme of the educational status scale, being categorized as "good" is similarly persistent. The number of counties exceeding the national percentage of college-educated adults remains constant at five, and four counties (Hamilton, Marion, Monroe, and Tippecanoe) are consistently members of that highest category. Lasting changes only occurred at the bottom of the scale with counties switching between medium and poor educational status category.

If the current transition rates will persist during the first decade of the 21st century, drastic improvements are unlikely. At the most, we will see very slow improvements at the bottom of the education scale. There will be no change at the top of the educational scale; the same five counties that already peak the educational scale in 2000 will continue to do so in 2010. We will see a few counties that had a medium education level in 2000, drop into the category of poor educational status, and the number of counties with a poor educational level will decline from 41 to 37.

The 87 Indiana counties that currently have a medium or poor educational status lag behind the national standard with respect to the percentage of highly educated residents. Catching up with the nation will be a particularly challenging task for the counties that are lagging many years behind the nation. In the year 2000, eleven counties are lagging by one to ten years, that is, their percent of well-educated residents is below the 2000 but above the 1990 national percentage. Five counties are lagging by 11 to 20 years: the percent of well-educated residents is below the 1990 but above the 1980 national percentage. Forty-four counties are lagging by 21 to 30 years: the percent of well-educated residents is below the 1980 but above the national percentage. The remaining 27 counties – that is, more than a

[5] Note that there is no county that has an above average percentage of residents with at least a four-year college degree and an above average percentage of residents without a high school diploma (upper right hand quandrant of the distribution).

quarter of all counties – are lagging by more than 30 years: the percent of well-educated residents is even below the 1970 national percentage (see Figure 2).

– Figure 2 about here –

A more nuanced assessment of the persistence in educational status is provided by an Index of Relative Educational Deprivation, *IRED*. The index places a county's educational status on a scale bounded by the national extremes in the percentage of highly educated residents and the percentage of poorly educated residents. IRED can be measured for each county i at time t, and is defined as:

$$IRED_{it} = 1 - \frac{D_{it} - D_{\min,t}}{D_{\max,t} - D_{\min,t}} \in [0,1]$$

where D_{it} is county i's deviation from the national percent of adults without a high school degree, P_t, plus its deviation from the national percent of adults with at least a 4-year college degree, G_t:

$$D_{it} = (P_t - P_{it}) / P_t + (G_{it} - G_t) / G_t$$

$D_{min,t}$ and $D_{max,t}$ are, respectively, the smallest and largest deviation from the national percentages.

The index varies from 0 to 1, with 0 indicating the least educational deprivation and 1 indicating the highest level of relative educational deprivation. Note that the standardization of the index via the minimum and maximum values of D_{it} are specific to the period t. Thus, for every year, $IRED_{it} = 0$ for the county with the highest educational status in that specific year, and $IRED_{it} = 1$ for the county with the lowest educational status at time t.

Figure 3 shows the distributions of relative educational deprivation for all U.S. counties and for the subset of Indiana counties in 1970 and 2000. Over time, many counties could improve their relative educational status. In fact, for all U.S. counties the average relative deprivation index declined from 0.732 in 1970 to 0.526 in 2000. Indiana followed this trend and the average relative deprivation is with 0.730 in 1970 and 0.512 in 2000 even slightly less than for the nation. Remarkable is also the – compared to the nation – substantially lower variation in the deprivation index across Indiana counties. Indiana counties are underrepresented among the least deprived counties as well as among the most deprived counties.

– Figure 3 about here –

In 1970, only three of the 92 Indiana counties are part of the top 10^{th}-percentile of the national distribution (the two university counties, Monroe and Tippecanoe, as well as the

suburban county Hamilton), and only seven are in the second 10th-percentile. In order to be well-represented at the top, Indiana should have a total of 18 rather than the observed 10 counties among the top 20% of the ranks. At the other end of the distribution, i.e., counties with the highest index of educational deprivation, Indiana's under-representation is even more pronounced. No Indiana county is among the bottom 10th-percentile and only two counties (Crawford and Switzerland) are placed in the second to the last 10th- percentile.

Thirty years later, in the year 2000, the overall pattern of relative educational deprivation has remained rather stable: counties that were highly deprived in 1970 continue to be so in 2000. For all U.S. counties the correlation amounts to r = +0.807, and for the subset of Indiana counties the correlation is slightly weaker with r = +0.779 (see Table 5). Thirty-five Indiana counties could improve their ranking but for 57 counties, the ranks declined. Floyd County leads the winners, moving up by 1108 ranks from the seventh to the third 10th-percentile. Most of that improvement took place during the 1970s, shortly after Indiana University's Southeast campus in New Albany had been established. Among the counties with declining ranks, Elkhart County leads the list: it dropped by 1044 ranks from the third 10th-percentile to the sixth 10th-percentile. Elkhart County is the sixth largest county in Indiana, economically strongly oriented towards manufacturing, and educational attainment levels being mostly dominated by a solid high school education rather than a university education. Overall, Indiana counties continue to be underrepresented in the top and bottom ranks, but their representation at both ends of the distribution increases. In 2000, 11 counties or 13 percent rank in the top 20th percentile of the national distribution; four counties even make the top 10th percentile. Most remarkable, Hamilton County which is part of the Indianapolis metropolitan area, now ranks 10th in the nation. But Indiana also increased its representation at the bottom of the scale. Five counties are now in the bottom 20th percentile, and Lagrange County even joins the bottom ten percent of the ranks. These trends suggest that while Indiana counties continue to dominate in the middle ranks, there is also a tendency towards an increasing disparity. In fact, while the average index of relative educational deprivation decreased over time, the standard deviation increased.

– Table 5 about here –

3.2 The Emergence of a Knowledge Agglomeration: 1970 to 2000. As shown in the previous section, Indiana counties vary widely in terms of their percentage of highly educated residents as well as in terms of their relative educational deprivation. This variation includes several distinct peaks of intellectual capital, and the following analysis will reveal that the counties with a strong intellectual basis exhibit a spatially clustered pattern. Equally

important, the spatially clustered pattern of the highly educated population intensifies over time and thus hints towards an emerging agglomeration of intellectual capital.

The highly educated segment of the population is neither uniformly distributed across Indiana's 92 counties nor does its spatial distribution mirror the distributions of the other educational attainment groups. The correlation coefficients reported in Table 6 suggest a persistent negative relationship between the percentage of very highly educated adults and very poorly educated adults. Interestingly, the negative association between the highly educated adults and those with a high school degree is a more recent phenomenon. In 1970, there was no relationship between the respective percentages, but by 2000 there was a nearly perfectly negative correlation. The only group that has a positive – albeit weakening – relationship with the highly educated population is the group of residents with some college education.

– Table 6 about here –

The well-known segregation index offers a straightforward means to assess the separation of two population groups across spatial units (Duncan and Duncan 19955a, 1955b; Massey and Denton 1988). It is defined as:

$$S = 50 \sum_{i=1}^{n} \left| \frac{A_i}{A} - \frac{B_i}{B} \right|$$

where A and B are the total population sizes of two groups across n spatial units $i = 1, \ldots, n$ and A_i and B_i are the respective population sizes of the two groups in county i. The segregation index varies between 0 and 100, with 0 signaling the absence of segregation and 100 signaling complete segregation.

Applied to the educational attainment groups, the segregation indices show that there is further evidence of the separation of the highly educated population from the population with lesser education (Table 6). The highly educated group is most segregated from the population with the least education. In 1970 the segregation index for the highly educated and those without a high school degree is 19, suggesting that 19 percent of the highly educated would need to relocate in order to achieve a spatial distribution identical to that of the population without a high school degree. This segregation level is twice as high as the segregation from the population with some college education. Over time, the segregation of the highly educated population from all other groups increases and has reached 23 percent for the separation from the poorly educated.

The segregation index is a-spatial in that it is irresponsive to changes in the spatial arrangement of the counties. As Figure 4 shows, however, the spatial distributions of the well-educated population as well as of the index of relative educational deprivation are characterized by distinct clustering that strengthened over time. In 1970, only the two counties housing the major universities – Indiana University in Monroe County and Purdue University in Tippecanoe County – emerge as peaks in the otherwise flat landscape of little intellectual capital. Both have a high percentage of college-educated residents yet are entirely surrounded by counties with a substantially weaker knowledge base. As a result of these two outliers, the spatial pattern is classified as random (Moran's I = –0.011).[6] During the subsequent 30 years, the counties in the Indianapolis metropolitan area – located between the two major universities – substantially increased their percentage of college-educated residents. Thus, by the year 2000, an agglomeration of intellectual capital had emerged, centered in the Indianapolis metro area and stretching northwest towards Tippecanoe County and southwest towards Monroe County. This development is reflected in the increasing positive spatial autocorrelation that – starting in 1990 – becomes significant. Locally, the center of the knowledge agglomeration (including Hamilton, Marion, Boone, Hancock, Hendricks, and Johnson counties) shows the highest level of positive spatial autocorrelation. Not surprisingly, at the edges of the knowledge agglomeration in Monroe County and Tippecanoe County, the local autocorrelation becomes negative. This increasing spatial clustering of counties with a strong knowledge base is opposite to the temporal changes in the spatial autocorrelation of the percent residents with poor education. In 1970, this variable showed a very strong spatial clustering (I = +0.462) but the clustering weakened during the subsequent decades.

– Figure 4 about here –

A more intuitive way of describing the emergence of the knowledge agglomeration in Indiana is by looking at the distribution of the educated population as a function of the distance from the agglomeration core. In 2000, the college-educated population lives – on average – 63 miles[7] away from Indianapolis, down from 66 miles in 1970. Thus, on average, the educated population lives within an area that includes the two limiting poles of the agglomeration – Tippecanoe County in the Northwest and Monroe County in the Southwest.

[6] The spatial autocorrelation analysis is performed using a row-standardized contiguity matrix where two counties are defined as neighbors if they share a common border of non-zero length.

[7] All distances are spherical distances between county midpoints.

Tracking the development of this knowledge agglomeration shows that the main push towards spatial concentration did not come until the 1980s. In 1970, slightly more than a quarter of the college educated population lived within a 25-mile radius around Indianapolis. By 1980 the share of knowledge workers within that radius had barely increased, but by 1990 it had risen to 30 percent and to about 33 percent by the year 2000.

Figure 5 shows the cumulative distributions of the college educated population for all distances from Indianapolis, for both 1970 and 2000. Over time, the cumulative percentages for the lesser distances moved upwards, suggesting an increasing concentration of the highly educated around the center of the state. Interestingly for very short distance (less than 16 miles, i.e., within the City of Indianapolis itself), the share actually decreased, suggesting that the highly educated residents prefer suburban locations (primarily Hamilton County) over a central city location. In comparison, the share of poorly educated residents within the proximity of Indianapolis is substantially smaller and remained nearly constant throughout the entire 30-year period. In fact, for the poorly educated population the 1970 and 2000 cumulative distributions with increasing distances from Indianapolis are almost identical. Moreover, the cumulative distribution of the poorly educated population lies below that of the highly educated population up to a distance of about 125 miles, suggesting that the poorly educated population continues to be left behind at the State's periphery, while the highly educated population increasingly concentrates in the emerging knowledge agglomeration centered about Indianapolis.

– Figure 5 about here –

3.2 The Influence of Rurality and Accessibility on Intellectual Capital Accumulation. In this section I assess the influence of rurality and accessibility on changes in the size of the highly educated population segment. The hypotheses to be tested are, first, that the degree of rurality negatively affects the growth of the highly educated population and second, that accessibility positively influences the growth of the highly educated population. Towards that end, the following model is estimated separately for each decade, using data for the 92 Indiana counties:

$$\ln \frac{y_{i,t+10}}{y_{i,t}} = \beta_0 + \beta_1 R_{i,t} + \beta_2 D_i + \beta_3 D_i^2 + \beta_4 \ln y_{i,t} + \beta_5 IRED_{i,t} + \varepsilon$$

Where $y_{i,t}$ is the number of highly educated residents in county i at time t (t=1970, 1980, 1990), $R_{i,t}$ is county i's degree of rurality at time t, measured on the rural-urban continuum

scale from 1 (least rural) to 9 (most rural),[8] D_i is the spherical distance from Indianapolis,[9] measured in miles, and $IRED_{i,t}$ is county i's index of relative educational deprivation as defined in section 3.1. The logarithm of the initial size of the college-educated population, $\ln y_{i,t}$ and the initial level of educational deprivation, $IRED_{i,t}$, serve as control variables. The quadratic distance expression is used as a proxy for accessibility and it is expected that the growth variable declines – at a declining rate – with increasing distance from Indianapolis. Finally, the slope parameter of rurality is expected to be negative.

– Table 7 about here –

Table 7 shows the estimation results for each decade. The model can explain more than a quarter of the variation, for the 1980/90 data even more than a third. Moreover, the hypothesized effects of rurality and accessibility can at least partially be confirmed, and we can extract four main results. First, the growth of the college-educated population is negatively and significantly affected by rurality. Thus, compared to urban counties, more rural counties experience a significantly smaller growth of their highly educated population. Interestingly, the magnitude of the estimated rurality effect is strongest during the 1970s. For the later decades, the rurality effect persists but weakens. For example, in 1970 a rise in rurality by one unit lowers the growth ratio $y_{i,1980}$ / y_{i1970} by about 4.4 percent, ceteris paribus. In contrast, during the 1980s the impact diminishes to a decline in the growth ratio by only 3.1 percent, and by 3.3 percent during the 1990s.

Second, the influence of accessibility to the Indianapolis metro area only becomes significant in the last decade, i.e., when the knowledge agglomeration was forming and strengthening. During the 1970s and 1980s, the distance parameters are not significantly different from zero. During the 1990s, however, the accessibility effect does become significant and the estimated distance parameters suggest that the growth of the highly educated population decreases – at a decreasing rate – up to a distance of about 75 miles from Indianapolis, before increasing again for counties that are located beyond this threshold. The entire knowledge agglomeration identified in section 3.2 lies within this 75-mile area.

Third, the initial size of the highly-educated population plays a role in the 1970s and 1990s, but not in the 1980s. In the 1970s and 1990s, the size effect is significantly negative,

[8] See http://www.ers.usda.gov/Data/RuralUrbanContinuumCodes/ for definitions and coding of counties on the rural-urban continuum.

[9] Let x and y be the radian of longitude and latitude for the Indianapolis centroid, and x_i and y_i be the radian of longitude and latitude of county I's centroid. Then the spherical distance, *Di*, from county i to Indianapolis is given by $D_i = 3959[\arccos(\cos(x-x_i)\sin(y)\sin(y_i)+\cos(y)\cos(y_i))]$.

but the estimated effect size is very small. That is, a one percent increase in the initial size is estimated to lower the growth ratio by 0.118 percent in the 1970s, and by 0.072 percent in the 1990s.[10] The initial level of educational deprivation is irrelevant in the 1970s. In the 1980s and 1990s, it has an estimated negative effect but only at a ten percent significance level. This suggests that – ceteris paribus – counties that already have a low educational status are further disadvantaged by lower growth rates.

Fourth, an interesting result is also derived from a spatial analysis of the residuals. During the 1970s, the residuals are randomly distributed across space (Moran's I = – 0.037). In the subsequent decades, the increase in Moran's I alludes to positive spatial autocorrelation that, in the 1990s, has become even highly significant. This is an important result in that it alludes to the hidden spatial information in the growth data for the knowledge population. It suggests that growth ratios for the highly educated population in one county are positively influenced by the growth ratio in neighboring counties. Indeed, preliminary results from a spatial lag model suggest that this type of spatial spillover is present (spatial autocorrelation coefficient of $\hat{\rho} = 0.564$ with t = 3.172), thereby reinforcing the conditions favoring the emergence of a knowledge agglomeration.

4. Conclusions

A knowledge–based workforce is a necessary albeit not sufficient condition for successful competition in today's economy. This paper thus aimed at contributing to our understanding of temporal changes in the distribution and accumulation of intellectual capital, using the State of Indiana as a case study. Specifically, the paper addressed three core questions: Did the distribution of intellectual capital across Indiana counties change over time and does it differ from the distribution across all U.S. counties? Do brain-rich areas concentrate in space and did the degree of concentration increase over time? Are degree of rurality and accessibility related to an area's ability to accumulate intellectual capital?

The analysis shows that Indiana participated in the educational boom that led to a nationwide increase in educational attainment levels over time. Indiana also increased its share of college-educated residents and lowered its share of residents who have not completed high school. However, on average, Indiana is lagging behind the nation, and the gap between Indiana and the nation has been widening. Interestingly, Indiana counties are under-represented among the nation's leading counties as well as among counties with a severely deprived education status. Nevertheless, educational attainment levels in more than

[10] Note that these estimates suggest a very slow rate of convergence (Abreu et al. 2005). For the last decade, for

a quarter of Indiana counties are lagging behind the national averages by more than 30 years. At the other end of the distribution, Indiana's educationally least deprived counties could solidify or even improve their status over time. Over time, this led to an increasing disparity in educational attainment levels across Indiana counties as well as a disturbing persistence of relative educational deprivation for many counties. In light of these results, the recently released strategic plan for economic development in Indiana sounds overly optimistic when stating: "Indiana will have an abundant supply of highly skilled and educated workers that meet the demands of businesses" (Indiana Economic Development Council Inc., 2005, p. 5).

Spatially, the distribution of the highly educated population has become increasingly concentrated in the center of the state, along an axis that stretches from Tippecanoe County to the Indianapolis metropolitan area and continues to extend to Monroe County. While the corner stones of this axis have a long tradition with Purdue University in Tippecanoe County and Indiana University in Monroe County fueling their favorable educational standing, the improvements in educational standing of the counties in and around the Indianapolis metropolitan area is remarkable. Thus, by the year 2000 a knowledge agglomeration has emerged that contributes to an increasing spatial disparity of intellectual capital across Indiana's counties. The analysis further suggests that growth of the knowledge population is favorably influenced by closeness to the knowledge agglomeration, but negatively influenced by rurality and educational deprivation. Moreover, it suggests that counties experience higher growth of their highly educated population if they neighbor counties with a high growth of their knowledge population.

These results imply future developments that pose potentially severe challenges to peripherally located counties. They are at high risk of being further left behind. Yet, the implied future developments also offer promising opportunities for the knowledge agglomeration in the center of the State, with a prospect for unprecedented economic growth involving R&D and innovation. Moreover, the literature repeatedly confirms the importance of spatial spillovers in today's knowledge economy (Zucker et al. 1998, Karlsson 2004, Greunz 2004, Poot 2004). Thus, further economic growth in Indiana's knowledge agglomeration has the potential to positively affect more peripheral locations, and thus eventually benefit the entire state.

In light of these benefits, the State of Indiana may be well-advised to adapt a new regional perspective that assigns a special status to this knowledge agglomeration and invest

instance, the convergence rate amounts to $\lambda = \ln(\beta+1)/(-10) = 0.0075$ and a half-life of 93 years.

in improved infrastructure needed to facilitate the location of new firms and enterprises. For example, since the knowledge economy is a network economy, improved transportation infrastructure is of particular importance (Van Oort and Raspe 2005). Such improved transportation is needed within the agglomeration, particularly to the south of Indianapolis. Yet, improved transportation infrastructure should also benefit Indiana's connection to knowledge agglomerations throughout the nation. Currently, the State of Indiana has a peripheral spatial position relative to the main centers of knowledge worker concentration: the average distance to the ten metropolitan areas that gained the most brain power between 1995 and 2000, exceeds 1,000 miles. This long distance to knowledge centers positions Indiana at the spatial periphery or even beyond the reach of knowledge spillover. An airline network with improved connectivity to other knowledge centers around the nation could substantially alleviate this locational disadvantage.

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Table 1. Percent of Population (age 25+) with Highest and Lowest Educational Attainment Levels: U.S. 1970 to 2000

Year	% of population with at least a four–year college degree		% of population without a high school degree	
	United States	Indiana	United States	Indiana
1970	10.7	8.3	47 7	47.1
1980	16.2	12.5	35.5	33.6
1990	20.3	15.6	24.8	24.4
2000	24.4	19.4	19.6	17.9

Source: U.S. Census Bureau, Statistical Abstract of the United States, various years

Table 2. Net Migration of Single College–educated Adults age 25 to 39, 1995–2000

U.S. State	Single college–educated population, aged 25 to 39 in 2000	Net migration of single college educated population age 25 to 39		Half–live (years before population is halved, assuming constant migration rates)
		Absolute	Rate (%) *	
Iowa	43206	–11,691	–22.0	13.9
Indiana	90632	–14,334	–14.2	22.6
Wisconsin	96008	–11,224	–10.8	30.4
Ohio	198126	–18,409	–8.8	37.5
Michigan	178216	–16,018	–8.7	38.2
Kentucky	53485	–3,411	–6.2	54.2
Illinois	331521	3,834	+1.24	NA

Source: Compiled using special tabulations of the U.S. census Bureau, 2004
* per 100 persons of the 1995 population.

Table 3. Net Migration of Single College–educated Adults age 25 to 39, Indiana Metropolitan Areas, 1995–2000

Area	Single College–educated Population, age 25–39, 2000	Migrants 1995–2000			5–year net migration rate (%)
		into the metro area	out of the metro area	Net	
Indianapolis, IN MSA	37,527	13,138	8,948	+4,190	+13.0
Elkhart–Goshen, IN MSA	1,693	601	638	–37	–2.3
Kokomo, IN MSA	1,121	432	552	–120	–10.2
South Bend, IN MSA	4,485	1,727	3,544	–1,817	–29.9
Lafayette, IN MSA	4,714	1,821	5,631	–3,810	–49.0
Bloomington, IN MSA	5,632	2,712	7,793	–5,081	–51.7
Muncie, IN MSA	1,773	649	2,674	–2,025	–53.9
Multi–state Metro Areas					
Chicago–Gary–Kenosha, IL–IN–WI CMSA	290,324	70,971	52,221	+18,750	+7.3
Louisville, KY–IN MSA	19,470	5,664	4,722	+942	+5.3
Cincinnati–Hamilton, OH–KY–IN CMSA	40,070	11,493	13,319	–1,826	–4.5
Evansville–Henderson, IN–KY MSA	3,616	1,183	1,605	–422	–10.6

Source: Compiled using special tabulations of the U.S. Census Bureau, 2004

Table 4. Ten–year Transition Rates for Indiana Counties' Educational Status Categories, 1970 to 2000*

Educational Status	Number of Counties	Educational Status			Number of Counties
		Transition Rates			
	1970	1970 to 1980			1980
Poor	55	0.93	0.05	0.02	59
Medium	32	0.25	0.75	0	28
Good	5	0	0.20	0.80	5
		Transition Rates			
	1980	1980 to 1990			1990
Poor	59	0.93	0.07	0	56
Medium	28	0.04	0.93	0.04	31
Good	5	0	0.20	0.80	5
		Transition Rates			
	1990	1990 to 2000			2000
Poor	56	0.57	0.43	0	41
Medium	31	0.29	0.71	0	46
Good	5	0	0	1	5

* The educational status categories are defined as follows:
Poor: % without high school diploma: above average; and % with 4+–yrs college: below average
Medium: % without high school diploma: below average; and % with 4+–yrs college: below average
Good: % without high school diploma: below average; and % with 4+–yrs college: above average

Table 5. Index of Relative Educational Deprivation, IRED, 1970 to 2000

	U.S. Counties (n=3148)		Indiana Counties (n=92)	
	1970	2000	1970	2000
Least Deprived	Los Alamos, NM: 0.0	Falls Church, VA: 0.0	Monroe: 0.292	Hamilton: 0.127
Most Deprived	Wade Hampton, AK: 1.0	Starr, TX: 1.0	Crawford: 0.852	Lagrange: 0.746
Average	0.737	0.526	0.730	0.512
Standard Deviation	0.113	0.128	0.080	0.087
Coefficient of Variation	0.153	0.242	0.110	0.171
Correlation between 1970 and 2000 IRED	0.807		0.779	

Table 6. Spatial Autocorrelation, Correlation and Segregation between Adults with at least a 4–year college degree and Adults of other Educational Attainment Groups, Indiana Counties 1970 to 2000

		1970	1980	1990	2000
Correlation Coefficient of % adults with at least a 4–year college degree and % adults:	without a high school degree	–0.62	–0.68	–0.72	–0.68
	with a high school diploma	–0.06 [a]	–0.36	–0.72	–0.83
	with some college education	0.72	0.72	0.66	0.45
Segregation Index of adults with at least a 4–year college degree and adults	without a high school degree	19	19	22	23
	with a high school diploma	17	17	21	23
	with some college education	9	9	12	14
Moran's I	% residents without a high school degree	0.462	0.421	0.337	0.252
	% residents with at least a 4–year college degree	–0.011[b]	0.060[b]	0.103	0.113

[a] not significantly smaller than zero
[b] not significantly greater than the expected value for a random spatial pattern

Table 8. Parameter Estimates (t-statistics in parentheses) for Growth Ratio Models of the Highly Educated Population, 1970 to 2000.

Variable	1970 to 1980	1980 to 1990	1990 to 2000
Constant	1.808 (4.495)	0.649 (2.729)	1.329 (5.320)
Rurality *R*	–0.045 (–3.802)	–0.031 (–3.726)	–0.033 (–4.523)
Distance *D*	–0.00420 (–1.450)	–0.00097 (–0.519)	–0.00429 (–2.086)
Squared Distance D^2	0.000027 (1.511)	0.000008 (0.714)	0.00003 (2.316)
Size *ln y*	–0.118 (–4.334)	–0.007 (–0.419)	–0.072 (–4.030)
Educational Deprivation, *IRED*	–0.036 (–0.113)	–0.276 (–1.500)	–0.305 (–1.480)
n	92	92	92
R^2	0.263	0.358	0.278
Moran's I: Residuals	–0.037 (–0.399)	0.080 (1.388)	0.177 (2.873)

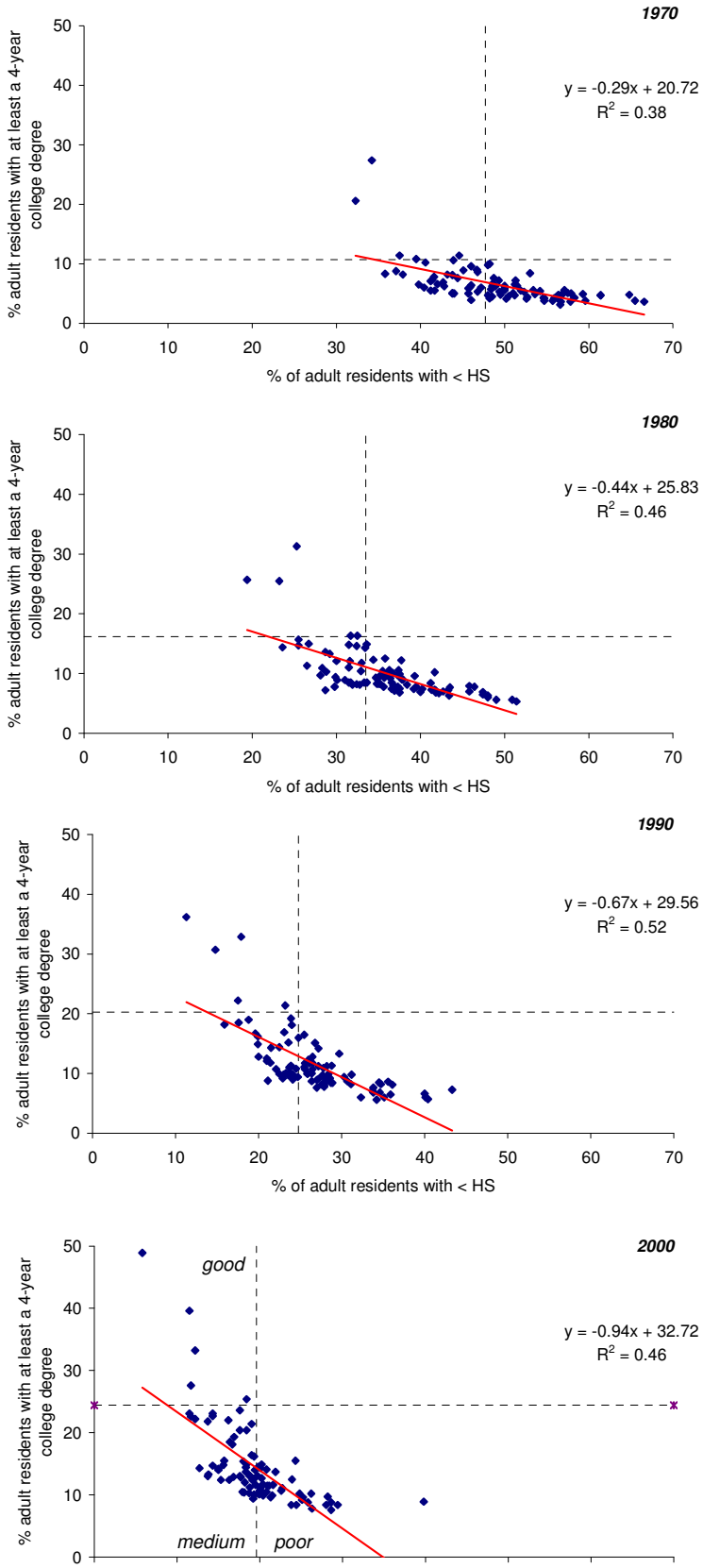
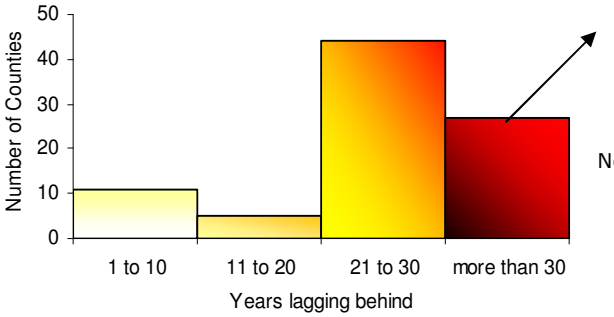


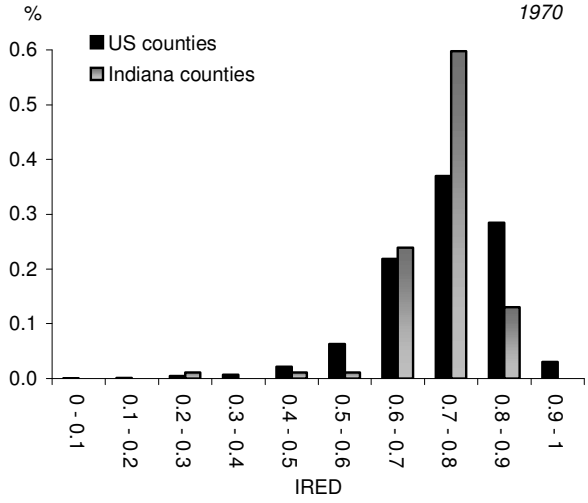
Figure 1. Indiana Counties by Percent of Adults with Less than High School Education and Percent of Adults with at Least a Four-year college degree, 1970 to 2000 (the dashed lines indicate the U.S. percentages).



1970 national percentage of college-educated residents: 10.6%

In the year 2000, 27 Indiana counties lagged behind the 1970 national percentage:
Greene and White: 10.5%; Miami: 10.4%
Blackford, Fulton, Pulaski and Rush: 10.3%
Orange and Washington: 10.2%
Clinton and Fountain: 10.1%
Jay and Randolph: 9.9%; Daviess: 9.7%
Newton and Perry: 9.6%; Sullivan: 9.4%; Owen: 9.2%
Lagrange: 8.9%; Martin and Scott: 8.8%
Crawford, Jennings, Pike, and Starke: 8.4 %
Fayette 7.8 %; Switzerland 7.6 %

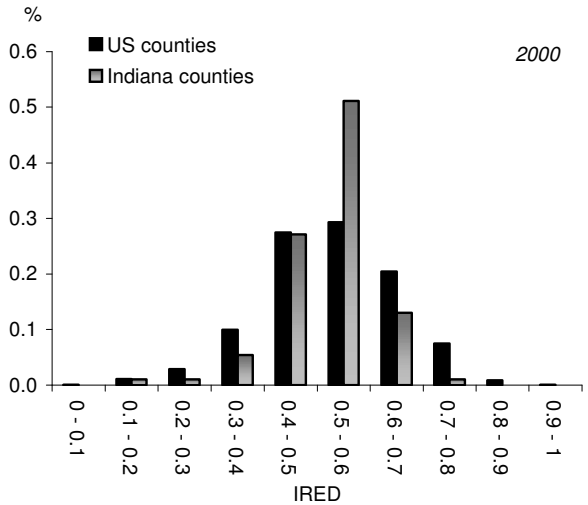
Figure 2. Indiana Counties by Years Lagging behind the National Education Level



Relative Educational Deprivation in 1970

Ten least deprived counties:
Nation: Los Alamos, NM; Pitkin, CO; Montgomery, MD; Williamsburg, VA; Fairfax, VA; Johnson, IA ; Arlington, VA; Benton, OR; Story, IA; Orange, NC
Indiana: Monroe (18), Tippecanoe (44), Hamilton (294), Porter (367), Marion (400), Allen (436), Bartholomew (470), Steuben (495), Hendriks (518), Montgomery (598)

Ten most deprived counties:
Nation: Wade Hampton, AK; Glascock, GA; Loving, TX; Bland, VA; Jackson, TN; Grundy, TN; Clay, WV; Twiggs, GA; van Buren, TN
Indiana: Crawford (2745), Switzerland (2675), Franklin (2471), Owen (2432), Washington (2420), Starke (2380), Vermillion (2323), Scott (2319), Ohio (2239)



Relative Educational Deprivation in 2000

Ten least deprived counties:
Nation: Falls Church, VA; Los Alamos, NM; Pitkin, CO; Douglas, CO; Arlington, VA; Howard, MD; Boulder, CO; Fairfax, VA; Montgomery, MD; Hamilton, IN
Indiana: Hamilton (10), Monroe (76), Tippecanoe (141), Boone (232), Hendriks (340), Porter (359), Hancock (398), Johnson (457), Allen (469), Warwick (474)

Ten most deprived counties:
Nation: Starr, TX; Kalawao, HI; Maverick, TX; Zavala, TX; Hudspeth, TX; Presidio, TX; McDowell, VA; Willacy, TX; Magoffin, KY
Indiana: Lagrange (3088); Crawford (2659), Switzerland (2641), Scott (2582), Starke (2565), Daviess (2512), Fayette (2484), Martin (2394), Orange (2349), Owen (2317)

(in parentheses: national rank from 1 (least deprived) to 3148 (most deprived)

Figure 3. Distribution of the Index of Relative Educational Deprivation (IRED), 1970 and 2000

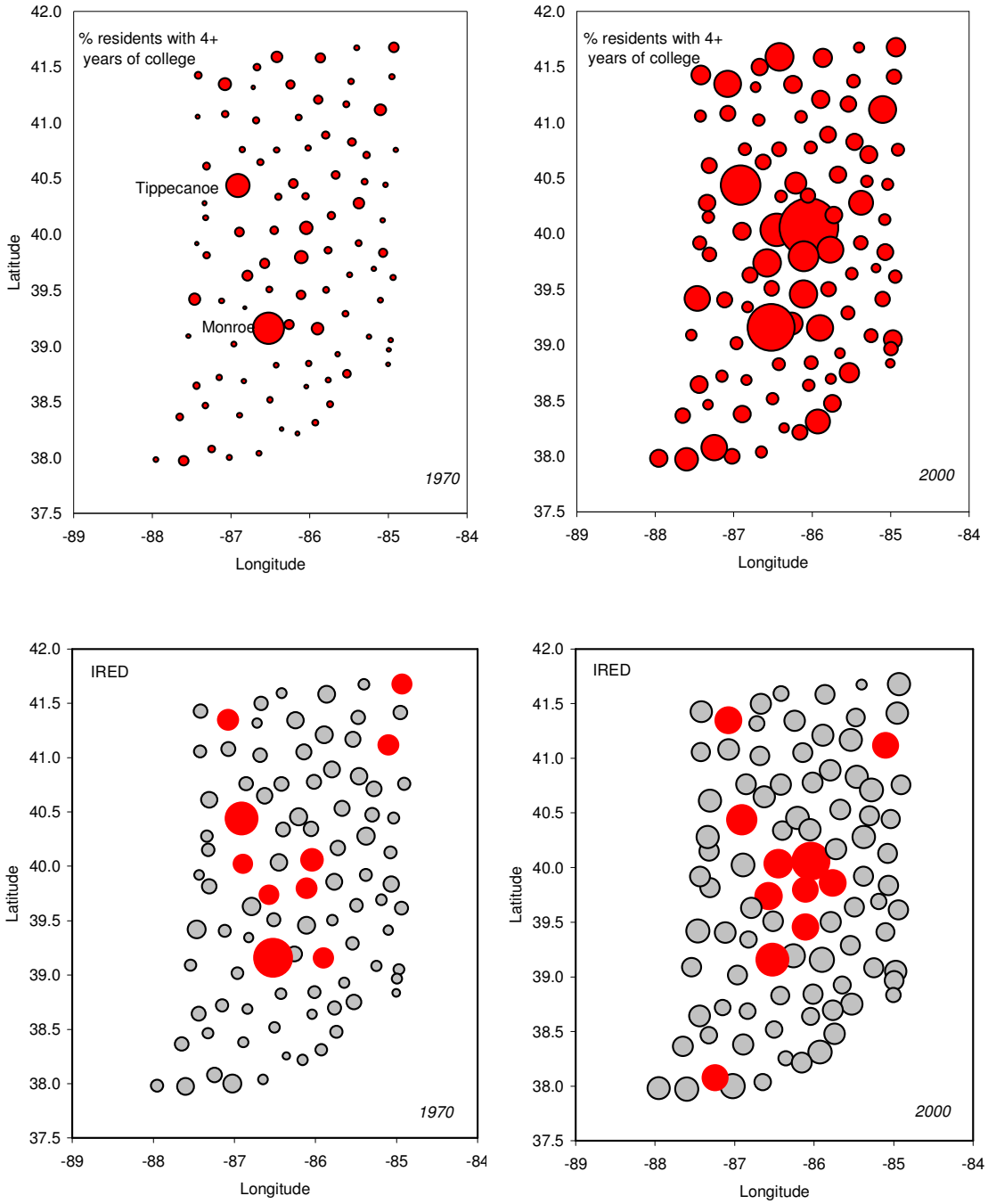


Figure 4. Landscape of Intellectual Capital, Indiana Counties 1970 and 2000.
Top: Percentage of county residents with at least a 4–year college degree (the bigger the circle, the higher the percentage). Bottom: Index or relative educational deprivation (the bigger the circle, the less the deprivation). Counties that rank in the national top–20 percentile of least deprived counties are marked in red.

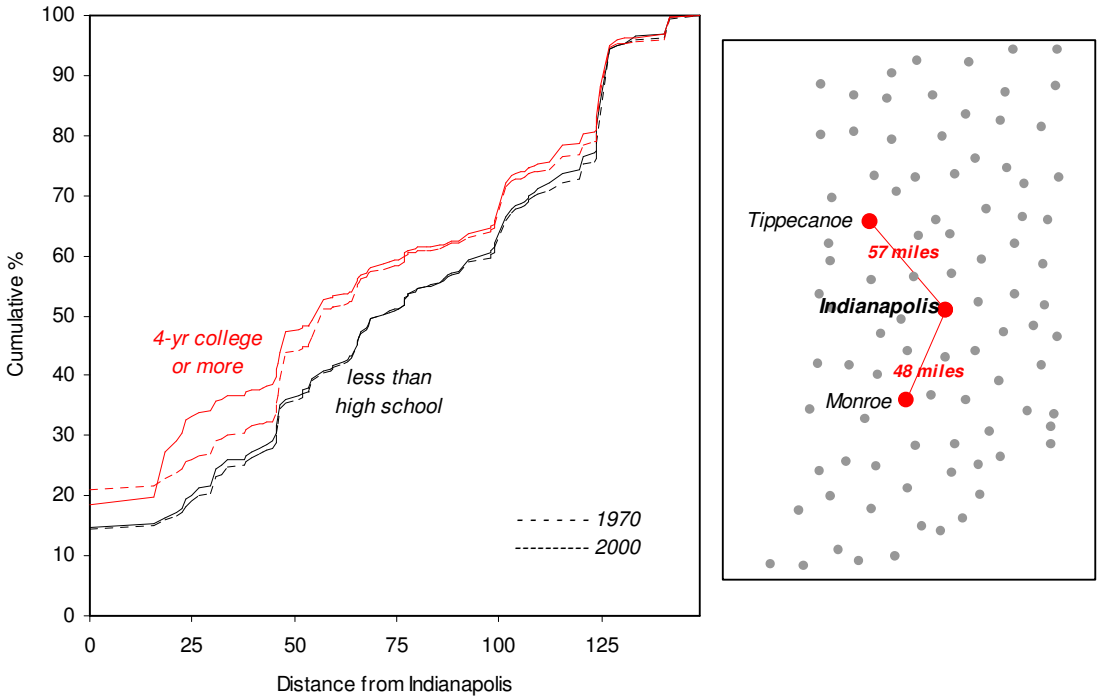


Figure 5. Cumulative Percent Share of the Highly Educated (4+–yr of college) and Poorly Educated (less than high school) with Increasing Distance from Indianapolis, 1970 and 2000.